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(54) **Cast polyurethane composition**

(57) The present invention relates to a cast polyurethane obtainable by a process comprising reacting (a) a polydiene polyol having a number average molecular weight between 500 and 500,000 with (b) an isocyanate or isocyanate prepolymer having two or more isocyanate groups per molecule, and then curing the reaction product with an aromatic curing agent which has low polarity as determined by a solubility parameter of less than 10.5. Preferably, the polydiene polyol is a hydrogenated polybutadiene diol. The present invention further relates to articles containing the cast polyurethanes.

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Description

This invention relates to a cast polyurethane composition.

Cast and thermoplastic polyurethane compositions based on the reaction of polyisocyanates with polymeric diols are well known for use as elastomers, adhesives, sealants, elastomeric surface coatings, and coatings for metals and plastics. Cast elastomers are often used by molders to make high temperature resistant elastomers for specialty applications because the crosslinking produced by the amine or multifunctional polyol curing agents provides good resistance to creep and flow at high temperatures. However, cast elastomers based on traditional soft segments such as polyester or polyether diols typically have poor resistance to hydrolysis.

Polyurethane cast elastomers are typically made by one of two processes: one-shot, or prepolymer. The one-shot process is a single step process in which the isocyanate, polydiene diol, amine curing agent, and optional chain extenders are mixed then cured in a mold to form the finished article.

More commonly, the two step prepolymer process is used. In the first step a prepolymer is made by reacting the isocyanate with the polydiene diol and, optionally, a chain extending diol to form an isocyanate capped prepolymer. In the second step this prepolymer is then reacted with one or more amine curing agents and, optionally, additional isocyanate. This mixture is then cured in a mold to form the finished cast elastomer article. Cast elastomer articles are typically post cured to achieve final properties. Additional isocyanate may be added in the second step to adjust the hard segment content of the elastomer, allowing a single prepolymer to be used to make materials with a wide range of hardnesses. The term hard segment content refers to the fraction of the composition that consists of the amine curing agent, optional chain extenders, and all of the isocyanate, both from the prepolymer and any added in the final step. The soft segment refers only to the polydiene polymer component. Because the final cast elastomer is crosslinked it is not necessary that the functionality of the polymeric diol or the isocyanate be exactly two.

The most common amine crosslinkers (curing agents) used in making cast elastomers are highly polar aromatic amines such as methylene bis(2-chloroaniline) (MCBA). When standard curing agents such as MCBA are used to try to make cast elastomers with polydiene polyols, the materials produced have poor properties. When exposed to hot water aging, the properties improve rather than degrading, indicating poor initial cure.

It is an object of the present invention to provide cast polyurethane compositions with excellent properties using, preferably hydrogenated, polydiene polyols. We have now found amine curing agents with low polarity form excellent cast elastomers with polydiene polyols and polyisocyanates. We have shown that these materials have hydrolysis resistance far beyond industry standard materials.

Therefore, the present invention relates to a cast polyurethane obtainable by a process comprising reacting (a) a polydiene polyol having a number average molecular weight between 500 and 500,000 with (b) an isocyanate or isocyanate prepolymer having two or more isocyanate groups per molecule, and then curing the reaction product with an aromatic curing agent which has low polarity as determined by a solubility parameter of less than 10.5.

The polydiene polyol is preferably hydrogenated to remove at least 90%, more preferably at least 95%, of the original olefinic unsaturation.

Polymers containing ethylenic unsaturation can be prepared by copolymerizing one or more olefins, particularly diolefins, by themselves or with one or more alkenyl aromatic hydrocarbon monomers. The copolymers, may, of course, be random, tapered, block or a combination of these, as well as linear, radial, or star.

The polymers containing ethylenic unsaturation or both aromatic and ethylenic unsaturation may be prepared using anionic initiators or polymerization catalysts. Such polymers may be prepared using bulk, solution or emulsion techniques. When polymerized to high molecular weight, the polymer containing at least ethylenic unsaturation will, generally, be recovered as solid such as a crumb, a powder, a pellet, or the like. When polymerized to low molecular weight, it may be recovered as a liquid such as in the present invention.

In general, when solution anionic techniques are used, copolymers of conjugated diolefins, optionally with vinyl aromatic hydrocarbons, are prepared by contacting the monomer or monomers to be polymerized simultaneously or sequentially with an anionic polymerization initiator such as group IA metals, their alkyls, amides, silanolates, naphthalides, biphenyls or anthracenyl derivatives. It is preferred to use an organo alkali metal (such as sodium or potassium) compound in a suitable solvent at a temperature within the range from about -150°C to about 300°C, preferably at a temperature within the range from about 0°C to about 100°C. Particularly effective anionic polymerization initiators are organo lithium compounds having the general formula



wherein R is an aliphatic, cycloaliphatic, aromatic or alkyl-substituted aromatic hydrocarbon radical having from 1 to about 20 carbon atoms and n is an integer of 1 to 4.

Conjugated diolefins which may be polymerized anionically include those conjugated diolefins containing from 4 to 24 carbon atoms, preferably 4 to 8 carbon atoms, such as 1,3-butadiene, isoprene, piperylene, methylpentadiene, phe-

nyl-butadiene, 3,4-dimethyl-1,3-hexadiene, and 4,5-diethyl-1,3-octadiene. Isoprene and butadiene are the preferred conjugated diene monomers for use in the present invention because of their low cost and ready availability. Alkyl(vinyl) aromatic hydrocarbons which may be copolymerized include vinyl aryl compounds such as styrene, various alkyl-substituted styrenes, alkoxy-substituted styrenes, vinyl naphthalene, and alkyl-substituted vinyl naphthalenes.

5 The polydiene polyols to be used in the cast polyurethanes of this invention are generally diols when the polydiene polymer is linear. When the polymers are diols, they will have up to about 2, preferably 1.8 to 2, most preferably 1.9 to 2, terminal hydroxy groups per molecule. Polydiene polyols with more hydroxy groups are also within the scope herein, i.e., if the prepolymer method is used, the total OH functionality should not be more than 3 but if the one shot method is used, the total OH functionality can be much higher since it is intended that the final composition will be highly crosslinked. Radial and star polymers are also contemplated herein and, in such case, the polymer would be polyols wherein a hydroxy group is located at the ends of most (that is >50%, preferably >80%, in particular >90% of the arms) or all of the arms of such polymers.

15 The polydiene polyols may have number average molecular weights of from 500 to 500,000. Lower molecular weights produce very stiff materials whereas higher molecular weights cause very high viscosity, making processing very difficult. More preferably, the polydiene polyol is one having a number average molecular weight of from 1,000 to 50,000. Even more preferably, the polydiene polyol is a polydiene diol having a number average molecular weight of from 500 to 20,000, more preferably 1,000 to 20,000, in particular a predominantly linear polydiene diol, because this offers the best balance between cost, ability to use the mildest curing conditions, and to achieve good processing behavior.

20 Hydrogenated polybutadiene diols are preferred for use herein because they are easily prepared and they have low glass transition temperatures, excellent hydrolysis resistance, and excellent weatherability. The diols, are synthesized by anionic polymerization of conjugated diene hydrocarbons with lithium initiators. Polyols containing more than 2 hydroxyl groups per molecule can be synthesized in the same manner. This process is well known as described in U.S. Patent Nos. 4,039,593 and Re. 27,145. Polymerization commences with a monolithium, dilithium, or polylithium initiator which builds a living polymer backbone at each lithium site. Typical monolithium living polymer structures containing conjugated diene hydrocarbons are:

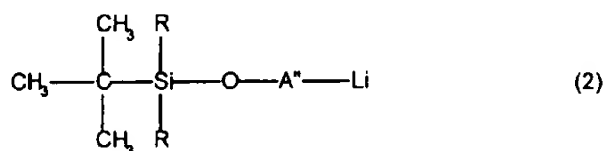
30 X-B-Li X-B₁-B₂-Li
X-A-B-Li X-A-B₁-B₂-Li
X-A-B-A-Li

wherein B represents polymerized units of one or more conjugated diene hydrocarbons such as butadiene or isoprene, A represents polymerized units of one or more vinyl aromatic compounds such as styrene, and X is the residue of a monolithium initiator such as sec-butyllithium. B can also be a copolymer of a conjugated diene and a vinyl aromatic compound. B₁ and B₂ are formed of different dienes.

35 Polydiene diols used in this invention may also be prepared anionically such as described in United States Patent Nos. 5,391,663; 5,393,843; 5,405,911; and 5,416,168. The polydiene diol polymer can be made using a di-lithium initiator, such as the compound formed by reaction of two moles of sec-butyllithium with one mole of diisopropenylbenzene. This diinitiator is used to polymerize a diene in a solvent typically composed of 90%w cyclohexane and 10%w diethyl-ether. The molar ratio of diinitiator to monomer determines the molecular weight of the polymer. The living polymer is then capped with two moles of ethylene oxide and terminated with two moles of methanol to yield the desired dihydroxy polydiene.

40 Polydiene diols can also be made using a mono-lithium initiator which contains a hydroxyl group which has been blocked as the silyl ether. Details of the polymerization procedure can be found in U.S. Patent 5,376,745. A suitable initiator is hydroxypropyllithium in which the hydroxyl group is blocked as the tert-butyl-dimethylsilylether. This monolithium initiator can be used to polymerize isoprene or butadiene in hydrocarbon or polar solvent. The living polymer is then capped with ethylene oxide and terminated with methanol. The silyl ether is then removed by acid catalyzed cleavage in the presence of water yielding the desired polymer.

45 A preferred method of making the preferred diol polymers of the present invention involves the use of lithium initiators having the structure:



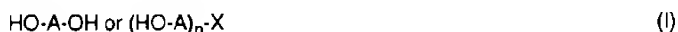
wherein each R is methyl, ethyl, n-propyl, or n-butyl and A* is an alkyl substituted or non-substituted propyl bridging group, including -CH₂-CH₂-CH₂- (1,3-propyl), -CH₂-CH(CH₃)-CH₂- (2-methyl-1,3-propyl) and -CH₂-C(CH₃)₂-CH₂- (2,2-dimethyl-1,3-propyl) or an alkyl-substituted or non-substituted octyl bridging group, including -CH₂-CH₂-CH₂-CH₂-CH₂-CH₂-CH₂-CH₂- (1,8-octyl), because these initiators will initiate polymerization of anionic polymers at surprisingly higher polymerization temperatures with surprisingly lower amounts of dead initiator (higher efficiency) than similar initiators wherein A* is replaced by alkyl-substituted or non-substituted butyl, pentyl, or hexyl bridging groups, such as CH₂-CH₂-CH₂-CH₂- (1,4-butyl), CH₂-CH₂-CH₂-CH₂-CH₂- (1,5-pentyl), or CH₂-CH₂-CH₂-CH₂-CH₂-CH₂- (1,6-hexyl).

An unsaturated polybutadiene polyol within the scope of this invention can have any butadiene microstructure. However, it preferably should have less than 10% 1,2-butadiene addition in order to minimize its viscosity. A polybutadiene polyol to be used after hydrogenation can also have any butadiene microstructure. However, it is preferred that it have no less than 30% 1,2-butadiene addition because, after hydrogenation, the polymer would be a waxy solid at room temperature if it contained less than 30% 1,2-butadiene addition and, when used in the process of this invention, it would give a semicrystalline solid at room temperature instead of an elastomer. Therefore, compositions based on a hydrogenated polybutadiene polyol having less than 30% 1,2-butadiene addition would have maintained at a temperature high enough during mixing to assure that the composition is a homogeneous liquid.

Although a hydrogenated polybutadiene having a 1,2-butadiene addition greater than 30% will give compositions within this invention which are liquids at room temperature, it is preferred that the 1,2-butadiene content should be between 30 and 70%, more preferably between 40 and 60% to minimize viscosity of the hydrogenated polybutadiene polyol.

When one of the conjugated dienes is 1,3-butadiene and is to be hydrogenated, the anionic polymerization of the conjugated diene hydrocarbons is typically controlled with structure modifiers such as diethylether or glyme (1,2-diethoxyethane) to obtain the desired amount of 1,4-addition. As described in Re. 27,145 the level of 1,2-addition of a butadiene polymer or copolymer can greatly affect elastomeric properties after hydrogenation. Similarly, linear unsaturated or hydrogenated isoprene polyol polymers should have greater than 80% 1,4-addition of the isoprene, preferably greater than 90% 1,4-addition of the isoprene, in order to reduce the viscosity of the polymer. Polyisoprene polyols of this type can be prepared by anionic polymerization in the absence of microstructure modifiers that increase 3,4-addition of the isoprene. The diene microstructures are typically determined by ¹³C nuclear magnetic resonance (NMR) in chloroform.

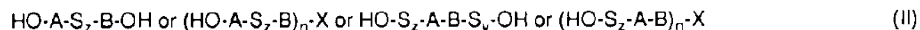
Certain polydiene polyols useful in the present invention have the structural formula



wherein A is a homopolymer of a conjugated diolefin monomer, a copolymer of two or more conjugated diolefin monomers, or a copolymer of one or more conjugated diolefin monomers with a monoalkenyl aromatic hydrocarbon monomer, where n ≥ 2 and where X is the residue of a coupling agent. Typically n ≤ 20, preferably ≤ 10, more preferably ≤ 4.

During the preparation of these polydiene polyols, it is possible to make some mono-functional polymer having the structural formula HO-A, either by incomplete capping of the living polymer or by incomplete coupling via the coupling agent. Although it is preferred that the amount of this mono-functional polymer is minimal, satisfactory crosslinked compositions within this invention can be achieved even when the amount of mono-functional polymer is as high as 50%w of the hydroxylated polymer in the composition.

Other polydiene polyols useful in the present invention have the structural formula



wherein A and B are polymer blocks which may be homopolymer blocks of conjugated diolefin monomers, copolymer blocks of conjugated diolefin monomers, or copolymer blocks of diolefin monomers and monoalkenyl aromatic hydrocarbon monomers, where S is a vinyl aromatic polymer block, where y and z are 0 or 1, where n ≥ 2, and where X is the residue of a coupling agent. Typically, n ≤ 20, preferably ≤ 10, more preferably ≤ 4.

These polymers may contain up to 60% by weight of at least one vinyl aromatic hydrocarbon, preferably styrene.

The A blocks and the B blocks can have a number average molecular weight of from 100 to 500,000, preferably 500 to 50,000, and most preferably 1,000 to 20,000. The S block which may have a number average molecular weight of from 500 to 50,000. Either the A or the B block may be capped with a miniblock of polymer, 50 to 1,000 number average molecular weight, of a different composition, to compensate for any initiation, tapering due to unfavorable copolymers rates, or capping difficulties.

The molecular weights of the polydiene polyols are conveniently measured by Gel Permeation Chromatography (GPC), where the GPC system has been appropriately calibrated. The polydiene polyols can be characterized from the data in the chromatogram by calculating the number-average molecular weight (M_n). The materials used in the columns of the GPC are styrene-divinyl benzene gels or silica gels. The solvent is tetrahydrofuran and the detector is a refractive index detector.

The polydiene polyols may be hydrogenated as disclosed in U.S. Patent Reissue 27,145. The hydrogenation may be carried out by a variety of well established processes including hydrogenation in the presence of such catalysts as Raney Nickel, noble metals such as platinum, soluble transition metal catalyst and titanium catalysts as in U.S. Patent No. 5,229,464.

The isocyanate used in this invention is an isocyanate having an average functionality of two or more isocyanate groups per molecule. Examples of suitable diisocyanates are 2,4-toluene di-isocyanate, 4,4'-diphenylmethane di-isocyanate, mixtures of isomers of diphenylmethane di-isocyanate, paraphenyldiisocyanate, isophoronediiisocyanate, 4,4'-methylene-bis(cyclohexylisocyanate), naphthalene di-isocyanate, hexamethylene di-isocyanate, isocyanates that have been extended by reaction to reduce volatility such as polymeric diphenylmethane di-isocyanate. Two or greater functionality isocyanate prepolymers made by reaction of an isocyanate with a difunctional chain extender may also be used.

The chain extenders that may optionally be added are low molecular weight, typically C_2 to C_{12} , diols having two hydroxyl groups per molecule. The preferred chain extenders have methyl, ethyl, or higher carbon side chains which make these diols more apolar and therefore more compatible with the apolar hydrogenated polydienes. Examples of such chain extenders are 2-methyl-1,3-propanediol, 2-ethyl-1,3-hexanediol, 2,2-dimethyl-1,3-pentanediol, 2-ethyl-2-butyl-1,3-propanediol, and 2,2,4-trimethyl-1,3-pentane diol. Linear chain extenders without carbon side chains such as 1,4-butane diol, and 1,6-hexane diol, also result in polyurethane Compositions if the components are well mixed or if a prepolymer method is used to improve compatibility.

Alternatively alkylene diamines having 2 to 12 carbon atoms may be used as chain extender.

Examples of suitable alkylene diamine chain extenders are ethylene diamine and hexamethylene diamine.

A preferred way to make cast elastomers is by the prepolymer method where an excess of the isocyanate component is reacted first with the polydiene polyol to form an isocyanate terminated prepolymer, which can then be reacted further with the amine curing agent of choice. The reaction with the curing agent can optionally include an additional isocyanate component to reach the desired hard segment content. The hard segment determines the stiffness of the final composition and consists of the isocyanate, curing agent and optionally any chain extending diol (or diamine).

For example, preferred hydrogenated polydiene diol based cast polyurethane compositions according to the invention can be prepared using a solventless prepolymer method or a solvent/prepolymer method as described in more detail below.

In the solventless prepolymer method, the hydrogenated polydiene diol is heated to at least 70°C, preferably less than 100°C, and then mixed with the desired amount of isocyanate. If the prepolymer reaction is slow, the addition of catalysts such as organo-tin compounds can substantially accelerate the reaction. The prepolymer is stored under nitrogen prior to heating to a temperature from 90°C to 100°C. The desired amount of amine curing agent, and optionally additional isocyanate, are added and thoroughly mixed before pouring into a heated mold treated with a mold release compound. The cast polyurethane elastomer composition is formed by curing in the mold at 80°C to 120°C for approximately one hour. Optionally, the composition can be postcured above 100°C for at least 2 hours.

In the solvent/prepolymer method, the polydiene diol is dissolved in a solvent, preferably dry toluene, typically heated to at least 70°C and not more than 100°C, and then mixed with the appropriate amount of an isocyanate having two or more isocyanate groups per molecule, and optionally a diol (or diamine) chain extender, for at least 1 hour under nitrogen flow. After the solvent is removed, the amine curing agent and optional additional isocyanate are added, mixed thoroughly, then poured into a preheated mold for curing and postcuring as described above.

In either case, the curing is done in the presence of an aromatic amine crosslinker with a relatively low polarity as determined by a solubility parameter of less than 10.5 (cal/cm³)^{0.5}. This ensures good compatibility which, in turn produces uniform materials with good physical properties. The most commonly used curing agent for conventional cast elastomer is methylene bis(2-aniline) (MCBA) which has a solubility parameter of 12.66. The solubility parameter is determined by the method described by Coleman, Graf, and Painter in their book Specific Interactions and the Miscibility of Polymer Blends, Technomic Publishing Company, 1991. This is a group contribution method in which the contribution of each segment of the molecule, such as -CH₂- or NH₂ which are based on a consistent set of molar values are combined to determine the solubility parameter of the total molecule. Hydrogen bonding interactions are not included

in this calculation. Curing agents which can be used to achieve the improved compositions of this invention are those which have a solubility parameter of less than 10.5. Examples of such curing agents are 4,4'-methylene bis(3-chloro-2,6-ethylaniline) available from Air Products Corporation and diethylene toluene diamine available from Ethyl Corporation. Preferably, the solubility parameter of the curing agents is at least 7.

5 A composition of the instant invention may contain plasticizers, such as oils used in conventional rubber compounds (rubber compounding oils). Unlike typical commercial cast elastomers based on polyether, polycarbonate, or polyester polyols, such oils can be used in the present cast elastomers because the polydiene polyol is a hydrocarbon rubber. Rubber compounding oils are well known in the art and include both high saturates content oils and high aromatics content oils. Preferred plasticizers are highly saturated oils (like Tufflo 6056 and 62024 oil made by Arco; Tufflo
10 is a trademark) and process oils (like Shellflex 371 oil made by Shell; Shellflex is a trademark). The amount of plasticizer employed in the invention composition can vary from 0 to 500 phr, preferably between 0 to 100 phr, and most preferably between 0 and 60 phr. If present, the plasticizer typically makes up at least 5 phr of the invention composition.

A wide variety of fillers, dyes, and pigments can be used in formulations with the present invention. Examples of suitable fillers include calcium carbonate, clays, talcs, zinc oxide, titanium dioxide, and silica. The amount of filler usually
15 is in the range of 0 to 800 phr, depending on the type of filler used and on the application for which the formulation is intended. Preferred fillers are silica and titanium dioxide. The filler should be thoroughly dried in order that adsorbed moisture will not interfere with the reaction between the polyisocyanate and the polydiene polyol.

Stabilizers known in the art may also be incorporated into the composition. These may be for protection during the life of the finished product against, for example, oxygen, ozone, and ultra-violet radiation. These may also be for stabilization against thermo-oxidative degradation during elevated temperature processing. Antioxidants and UV inhibitors
20 which interfere with the urethane curing reaction must be avoided. Preferred antioxidants are sterically hindered phenolic compounds like butylated hydroxy toluene. Stabilizers such as organic phosphites are also useful. Preferred UV inhibitors are UV absorbers such as benzotriazole compounds. The amount of stabilizer in the formulation will depend greatly on the intended application of the product. If processing and durability requirements are modest, the amount of
25 stabilizer in the formulation will typically be less than 1 phr. If the polyurethane product will be processed at high temperature or if the product must survive many years in service, stabilizer concentration could be as much as 10 phr.

Applications for cast elastomers are divided into high performance hot processing cast polyurethane elastomers and low performance room temperature processing cast polyurethane elastomers. High performance, high temperature cast polyurethane elastomer applications include: rolls (print rollers, coil coating rolls, paper mill rolls) wheels and tires
30 (for fork lifts, pallet wheels, casters, roller coaster wheels, and the like), mechanical goods (impellers, bearings, pads, belts, bushings, gaskets, gears, hoses, O-rings, pulleys, seals, sprockets, vibration mounts, valve liners, washers, and the like). Low performance applications include tire filling compounds, potting and encapsulants, pipe seals, athletic surfaces and rocket binders.

According to a further aspect, the present invention relates to articles containing the cast polyurethanes as
35 described herein

EXAMPLES

Chemicals

40 All chemicals used to make these cast elastomers are listed in Table 1. Polyols and chain extenders were dried under vacuum or 1-3mm Hg (0.13 - 0.4 kPa) at 70°C overnight prior to usage. Isocyanates were used as received from the suppliers. The toluene used in the reactivity study was dried over 4A molecular sieves for at least 24 hours prior to use.
45

Table 1

Materials Used to Make Cast Elastomers			
Designation	Chemical Identification	Eq. Wt	Supplier
KLP L-2203	Hydroxyl terminated poly(ethylene-butylene) oligomer	1753	Shell Chemical Co.
PTMO 2000	Poly(oxytetramethylene) glycol	1024	E. I. duPont de Nemours & Co.
PPG P-2010	Poly(oxypropylene) glycol	998	BASF Corporation
Poly-L225-28	Poly(oxypropylene) glycol	2000	Olin Chemical Co.
Mondur* M (MDI)	1,4-diphenylmethane diisocyanate	125	Bayer AG
Isonate* 143L	Carbodiimide-modified MDI	143	Dow Chemical Co.
PAPI-901	Polymeric MDI	132	Dow Chemical Co.
IPDI	Isophorone diisocyanate	111	Olin Corporation
TDI (Mondur*, TDS Grade II)	Toluene diisocyanate	87	Bayer AG
Desmodur* W	Methylene bis(4-cyclohexylisocyanate)	131	Bayer AG
HDI	1,6-hexamethylene diisocyanate	84	Bayer AG
1,4-BD	1,4-butanediol	45	GAF Corp.
1,6-HD	1,6-hexanediol	59	BASF Corp.
2-Ethyl-1,3-hexanediol	2-ethyl-1,3-hexanediol	73	Spectrum Chemical Mfg. Corp.
TMPD	2,2,4-trimethyl-1,3-pentanediol	73	Aldrich Chemical Co.
BEPD	2-butyl-2-ethyl-1,3-propanediol	80	Eastman Kodak Chemical Co.
HQEE	Hydroquinone di-(2-hydroxyethyl) ether	99	Eastman Kodak Chemical Co.
CURENE* -442 (MCBA)	4,4'-methylene bis(2-chloroaniline)	133	Anderson Development Co.
LONZACURE* M-CDEA	4,4'-methylene bis(3-chloro-2,6-diethylaniline)	190	Air Products
Designation	Chemical Identification	Eq. Wt.	Supplier
ETHACURE* 300	3,5-dimethylthio-2,4-toluenediamine/3,5-dimethylthio-2,6-toluenediamine	107	Albemarle Corporation
POLACURE* 740M	Trimethylene glycol di-p-aminobenzoate	157	Air Products
DETDA	Diethylene toluene diamine	89	Ethyl Corporation
T-12	Dibutyltin dilaurate		Air Products

* = trademark

The OH-number determination

The OH-numbers of the polydiene diols, and some reference polyols were determined by using three methods, proton nuclear magnetic resonance spectroscopy (^1H NMR), ASTM D-2849 (Method C), and by reaction with phenyl isocyanate. The OH-numbers determined by these methods were in good agreement, and especially the OH-numbers derived from the ^1H NMR and the phenyl isocyanate methods. In this case, the ASTM-2849 method was somewhat modified. After the reaction between phthalic anhydride and polyol at 105°C was completed, the titration of the remaining anhydride was carried out at 100°C instead at room temperature, as prescribed in the ASTM-2849 procedure. When

titration was carried out at room temperature, the hydrophobic hydrocarbon polyols precipitated and interfered with the titration. At 100° C, the polyol precipitation was significantly reduced.

Molecular weight determination

The average polyol molecular weight was determined by means of gel permeation chromatography and vapor pressure osmometry (VPO) method using an Osmomat (trademark) 070 instrument. The calibration was carried out by using benzil as a standard in toluene as a solvent. Toluene was used also as a solvent in the polyol molecular weight determination.

Compatibility

The compatibility of hydrocarbon-based polyols with the amine curing agents was studied by mixing the components at a specified weight ratio at 110°C. Visual observation of the mixtures at 110°C and after cooling at room temperature were recorded.

The physical and mechanical properties of polyurethane elastomers were determined by the following test methods:

- Shore hardness (ASTM D-2240-75)
- Stress-strain properties (tensile strength at break, ultimate elongation, 100% and 300% modulus).

The glass transition temperature (Tg) was measured by differential scanning calorimetry (DSC). The softening of polyurethane elastomers was measured by thermo-mechanical analysis (TMA).

The basic properties of diols (both of the invention and comparative commercial polyol PTMO 2000) which are utilized in this study are shown in Table 2. The number average molecular weight of KLP diols, as determined by the VPO method, was found to be in good correlation with the number average molecular weight calculated from the GPC data. All of these data were in good agreement with data supplied by the manufacturers.

Table 2

Properties of Polyols			
Polyol Type	KLP L-2203 Lab Scale	KLP L-2203 Commercial Scale	PTMO 2000
OH number (ASTM C-2849)	27.9	28.4	52.5
OH number (phenyl isocyanate method)	31.7	29.4	
OH Number (supplied by the manufacturer)	32.2	30.5	54.8
Molecular weight (VPO, g/mol)	3540	3250	2090
Molecular weight (GPC, g/mol)	3430	3330	2050
Viscosity at 20°C (cps, mPa.s)		50,000*	solid
Viscosity at 40°C (cps, mPa.s)		12,000	
Viscosity at 80°C (cps, mPa.s)		1200	
Tg (DSC, °C)	-50	-50	-70

*Typical viscosity for KLP L-2203.

The compatibility of mixtures of KLP L-2203 with aliphatic chain extenders at a 10:1 ratio also declined as polarity increased: 2,2,4 trimethyl 1,3-pentane diol (TMPD) ~ 2-butyl, 2-ethyl, 1,3 propane diol (BEPD) ~ 2-ethyl-1,3-hexanediol (compatible) > 1,6-hexanediol > 1,4-butanediol (partially compatible) > hydroquinone ethoxy ethanol (HQEE) (incompatible). Similarly, differences in polarity of aromatic amine crosslinkers affect their compatibility with KLP L-2203: diethylene toluene diamine (DETDA-solubility parameter-9.73) > 4,4'-methylene-bis(3-chloro-2,6-diethylaniline) LONZACURE M-CDEA-solubility parameter-9.81) > 3,5-dimethyl-2,4-toluenediamine/3,5-dimethylthio-2,6-toluenediamine (ETHACURE 300-solubility parameter-10.57) > 4,4'-methylene bis(2-chloroaniline) (MCBA, also, CURENE 442-solubility parameter-12.66) > trimethylene glycol di-p-aminobenzoate (POLACURE 740M-solubility parameter-11.69).

Table 3

Miscibility of KLP L-2203 Diol With Chain Extenders and Crosslinkers			
Chain extenders/crosslinkers	KLPL-2203/extender weight ratio	Temp. (°C)	Miscibility with KLP L-2203
CURENE 442	1/0.14	110	Phase separation
POLACURE 740M	1/0.15	140	Phase separation
ETHACURE 300	1/0.13	110	Clear and homogeneous
LONZACURE M-CDEA	1/0.16	110	Clear and homogeneous
DETDA	1/0.10	110	Clear and homogeneous
1,4-BD	1/0.06	80	Hazy
		105	Hazy, but clearer than at 80°C
1,6-HD	1/0.07	80	Hazy
		105	Hazy, but clearer than at 80°C
TMPD	1/0.08	80	Clear and homogeneous
BEPD	1/0.08	80	Clear and homogeneous
2-Ethyl-1,3-hexanediol	1/0.08	80	Clear and homogeneous
HQEE	1.0.09	130	Phase separation
HQEE+TMPD (up to 30% HQEE)		130	Phase separation

* = trademark

(The ratio by weight of polyol to chain extenders is calculated based on elastomer formulations at 22% hard segment and isocyanate index=104.)

Cast polyurethane elastomers were prepared utilizing the prepolymer method. In the first step, the NCO-terminated prepolymer was prepared by reacting toluene diisocyanate (TDI), or 4,4'-diphenylmethane diisocyanate (MDI) in Example 2, and polyol at an NCO/OH equivalent ratio of 2/1. The prepolymer synthesis was carried out by the following procedure: the TDI was placed in a 0.5L glass reaction kettle, which was equipped with a mechanical stirrer, thermometer, heating mantle, and a gas inlet and outlet for continuous flow of nitrogen. When the temperature of the isocyanate reached 70°C, the diol of the present invention (KLP L-2203) was added in several portions to the reactor under constant mixing. The reaction temperature was maintained at 70-80°C and periodic samples were withdrawn to determine the isocyanate content. After the theoretical NCO% value was reached, the reaction was stopped by cooling and the reaction product was stored in a sealed glass bottle under nitrogen. In the second step, a specified amount of free TDI (or MDI) as shown in Table 4 (the amount needed for 22% hard segment concentration) was added under vigorous mixing to the prepolymer which was preheated at 100°C. The chain extender (melted, if needed) was added to the prepolymer under vigorous mixing (30-40 sec.). At the gel point (2-3 min.), the mold was compressed to 20,000 psi (137.9 Mpa) for one hour at either 105°C or 115°C as noted in Table 4. The mold was then placed in an oven at 105°C or 115°C for 16 hours for postcuring.

The formulations and properties of KLP L-2203 based cast elastomers are shown in Table 4. The cast elastomers were prepared utilizing the above-described hindered aromatic amine crosslinkers: Examples 1-3 were cured with Lonzacure M-CDEA, Comparative Example C1 with Curene 442, Comparative Example C2 with Ethacure 300, and Comparative Examples C3 with Polacure 740M. (Lonzacure, Ethacure, and Polacure are trademarks) The reaction of prepolymer with DETDA was too rapid to allow preparation of testable samples, however, commercial equipment would be capable of making materials based on DETDA. Cast elastomers based on the least polar amine and the one with the lowest solubility parameter, Lonzacure M-CDEA, exhibited higher hardness and stress-strain properties than those based on MCBA or Ethacure 300. POLACURE 740M was so incompatible that early phase separation caused the resin not to cure. The lower properties of MCBA based elastomers was also due to poor compatibility with KLP L-2203.

Table 4

Properties of the Polyurethane Elastomers Based on KLP L-2203 Diol, TDI (or MDI) and Different Amino-Functional Chain Extenders by the Prepolymer Method at 1.05 Isocyanate to Amine Equivalent Ratio.						
Example	1	2	3	C1	C2	C3
Formulation (pbw)						
TDI Prepolymer (NCO/OH=2)	45		45	45	45	45
TDI	1.06		1.06	1.83	2.35	6.32
MDI Prepolymer (NCO/OH=2)		45				
MDI		0.565				
CURENE 442 (MCBA)				5.65		
ETHACURE 300					5.13	9.78
LONZACURE M-CDEA	6.42	4.93	6.42			
Hard segment (%)	22	22	22	22	22	33
Curing (1 hr) and Post Curing (24 hrs) Temperatures (°C)	115	115	105	115	105	105
Properties						
Hardness (Shore A)	74	71	73	59	60	69
Ultimate tensile strength, psi (MPa)	2160 (14.9)	2750 (19.0)	1620 (11.2)	1010 (7.0)	1450 (10.0)	1000 (6.9)
Elongation at break (%)	586	736	461	900	515	445
Modulus at 100% elongation, psi (MPa)	630 (4.3)	490 (3.4)	560 (3.9)	210 (1.4)	380 (2.6)	400 (2.8)
Modulus at 300% elongation, psi (Mpa)	1273 (8.8)	1022 (7.1)	1145 (7.9)	390 (2.7)	900 (6.2)	790 (5.5)
Softening Temperature (°C)	311	NR	204	NR	187	185

The tensile strength of cast elastomers based on Lonzacure M-CDEA and MDI (19.0 MPa) was higher than that based on TDI (19.9 MPa), as expected. The mechanical properties of the KLP L-2203 based cast elastomers were also affected by the curing temperature, e.g. the tensile strength of the Lonzacure M-CDEA/TDI based elastomers increased up to 33% when the curing temperature was increased from 105° to 115°C. The TMA softening temperature of Example 1 was very high, 300°C. The softening temperature of Example C2, Ethacure 300-based elastomers was lower, 188°C (curing temperature 105°C).

These cast elastomers show very clean phase separation between the soft and hard segments. This not only provides a very broad service temperature range but indicates that these materials will show low hysteretic heat build-up in high mechanical intensity applications such as rollers and tires.

Comparative Examples C4, C5, and C6 were made using conventional polyols by the same methods as Examples 1-3 and C1-C3. These properties are shown in Table 5. The water resistance of cast elastomers based on KLP L-2203, PPG 2000, PPG 400 AND PTMO 2000 was tested by measuring the change of mechanical properties upon immersion in 100°C (boiling) water for seven days (Table 5). The elastomers based on PPG diols and PTMO 2000 underwent almost complete failure. KLP L-2203 elastomers withstood this test very well. The Lonzacure M-CDEA-based elastomers exhibited a small decrease in the tensile strength (18%), due to plastization by water-an excellent retention of properties. The tensile strength of Ethacure 300 crosslinked elastomers increased somewhat (10%). In the latter case, this is most probably due to poor initial cure because of the slight incompatibility during curing. The strength of the MCBA

cured elastomer increased by 100% due to even poorer compatibility during cure

Table 5

The effect of aging in 100°C water for 7 days on Cast Elastomer Properties.						
Example	1	C2	C1	C4	C5	C6
Polyol	L-2203	L-2203	L-2203	PTMO 2000	PPG 2000	PPG 4000
Curing Agent	Lonzacure M-CDEA	Ethacure 300	MCBA	MCBA	MCBA	MCBA
Original Properties						
Hardness Shore A	74	60	59	89	86	75
Tensile MPa Strength (psi)	(2160) 14.9	(1450) 10.0	(1010) 7.0	(5410) 37.3	(1360) 9.4	(1480) 10.2
Elongation at Break (%)	590	520	900	450	700	1150
Properties after Aging						
Hardness Shore A	68	60	69	78	66	*
Tensile Mpa Strength (psi)	(1760) 12.1	(1660) 11.4	(2070) 14.3	(390) 2.7	(86) 0.6	*
Elongation at Break (%)	655	850	1050	110	18	*

* Sample underwent complete failure during aging

Claims

1. A cast polyurethane obtainable by a process comprising reacting (a) a polydiene polyol having a number average molecular weight between 500 and 500,000 with (b) an isocyanate or isocyanate prepolymer having two or more isocyanate groups per molecule, and then curing the reaction product with an aromatic curing agent which has low polarity as determined by a solubility parameter of less than 10.5.
2. The cast polyurethane of claim 1 wherein the polydiene polyol is a hydrogenated polybutadiene polyol.
3. The cast polyurethane of claim 2 wherein the hydrogenated polybutadiene polyol has no less than 30 percent by weight 1,2-butadiene addition.
4. The cast polyurethane of claim 3 wherein the hydrogenated polybutadiene polyol has from 40 to 60 percent 1,2-butadiene addition.
5. The cast polyurethane of claim 1 wherein the polydiene polyol is a hydrogenated polyisoprene polyol.
6. The cast polyurethane of claim 5 wherein the polydiene polyol has greater than 80 percent 1,4-isoprene addition.
7. The cast polyurethane of anyone of claims 1-6 wherein the polydiene polyol contains up to 3 hydroxyl groups per molecule.
8. The cast polyurethane of claim 7 wherein the polydiene polyol is a polydiene diol having up to 2 terminal hydroxyl groups per molecule.
9. The cast polyurethane of claim 8 wherein the polydiene diol has from 1.8 to 2 hydroxyl groups per molecule.
10. The cast polyurethane of claim 8 or 9 wherein the polydiene diol has a number average molecular weight from 500 to 20,000.

11. The cast polyurethane of anyone of claims 1-6, wherein the polydiene polyol is a radial or star polydiene polyol having terminal hydroxyl groups on most or all of the arms.

12. Articles containing the cast polyurethanes according to any one of the preceding claims.

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European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 97 20 2834

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Place of search THE HAGUE		Date of completion of the search 19 January 1998	Examiner Van Puymbroeck, M
CATEGORY OF CITED DOCUMENTS		T theory or principle underlying the invention E earlier patent document, but published on or after the filing date D document cited in the application L document cited for other reasons S member of the same patent family, corresponding document	
X particularly relevant if taken alone Y particularly relevant if combined with another document of the same category A technological background U non-written disclosures F intermediate document			

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